Indoor and Built Environment

Composition of Household Dust in Semi-urban Areas in Malaysia

Mohd Talib Latif[a]   Mohamed Rozali Othman[b]
Chong Lee Kim[a]   Siti Aminah Murayadi[a]
Khairul Nazri Ahmad Sahaimi[a]

[a]School of Environment and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia
[b]School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia

Abstract

A study of household dust composition was conducted in a semi-urban area around Kajang and Bandar Baru Bangi Selangor, Malaysia. Samples of household dust were collected from 31 randomly selected houses using a vacuum cleaner equipped with a changeable dust bag. Parameters analysed were anions (Cl^-, SO_4^{2-}, and NO_{3-}), cations (K^+, Ca^{2+}, and Mg^{2+}), and heavy metals (Cd, Fe, Ni, and Pb) to deduce the possible sources and evaluate the toxicity of indoor dust. The concentration of each parameter was compared to the concentration of street dust collected outside the houses. The results showed that the composition of anions was dominated by Cl^- followed by SO_4^{2-} and NO_3-; cations concentration by the sequence of $Ca^{2+} > K^+ > Mg^{2+}$ and for heavy metals concentration, Pb was present in the highest concentration followed by $Ni > Fe > Cd > Zn$. The study also showed that the concentration of most parameters analyzed were higher in household dust than street dust, suggesting that the composition of household dust is more closely related to indoor activities and the environment.

Introduction

In modern urban and semi-urban societies, indoor air quality has gained greater attention in recent years, chiefly due to the large amount of time we spend indoors or in microenvironments [1,2]; Jenkins et al. [3] showed that urban people spend an average of 87% indoors and only a mere 6% outdoors. It is acknowledged that there are hundreds of pollutants which affect indoor air quality and thousands of sources [4]. In fact, research indicates that there are more than 900 different contaminants present in indoor environments, depending on the particular operations and activities that occur within the specific environment [5]. These indoor air pollutants can be influenced from a surprising number of sources in the

Mohd Talib Latif,
School of Environment and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
Tel: +00 6 03 89213822, Fax: +00 6 03 89213357, E-Mail talib@ukm.my

indoor environment itself as well as from outdoor pollution [6–10].

Indoor dust is a heterogeneous mix of particles of organic and inorganic origin. The particles vary in size and shape, from large hair and textiles fibers to ultra fine particles [11,12]. Research dealing with these define outdoor and indoor specific sources for these elements [13–15]. Inorganic ions provide important information on the origin of the aerosols or dust composition and are commonly employed in source identification and apportionment studies. Calcium and magnesium (Ca^{2+} and Mg^{2+}) may indicate crustal or dust nature and potassium (K^+) as tracer for biomass burning and meat cooking [16,17]. Nitrate and sulphate (NO_3^- and SO_4^{2-}) are often higher in aerosols collected from urban areas and more related to combustion activities [16,18–20]. Adgate et al. [21] showed that tracked encrusted materials and deposited airborne particles were responsible for two-thirds of heavy metals including, Pb found in house dust. Fergusson and Kim [22] proved that worn furnishing, construction, cosmetic materials, paint chip and carpet materials could lead to an elevated heavy metals content. Smoke from cooking and smoking have also been found to distribute several gases and organic matter [23]. Furthermore, indoor dust carries viruses, bacteria, and gases [24].

Indoor dust may contain sufficiently large amounts of some elements to pose a considerable toxicological risk to more vulnerable groups of dwellers, e.g, younger children [2,25–27]. Other potential hazards are size, shape, surface area, mass, number chemical composition, and biological effects. Smaller particles have lower deposition velocities than coarse particles, and hence can remain in the air for a longer time, potentially impacting human respiration [28,29].

This study analyzed the composition of household dust and compared its composition to the main expected sources of indoor dust in semi-urban area in Malaysia, namely street dust. This study also sought to correlate the composition of household dust to the main sources of indoor air pollution such as smoking and cooking activities as well as to relate dust composition with the distance of the house from major roads.

Experimental

Household Dust and Street Dust Sampling

Samples of household dust were collected from 31 randomly selected houses (sampling twice per house) (Table 1) from several semi-urban housing areas in Kajang and Bandar Baru Bangi, Selangor, Malaysia. The samples were collected from living rooms using a vacuum cleaner equipped with a changeable dust bag as advised by Rasmussen et al. [30]. Street dust samples were collected at the roadside near each residence using a clean dust pan from $1\,m^2$ section of road directly adjacent to the residential property; typically 5–10 m from the house itself. The dust samples were sieved using stainless steel sieves with aperture size $< 63\,\mu m$ (lower size limit expected $> 0.01\,\mu m$) [31]. To eliminate cross contamination of the samples, the dust bag was changed and the vacuum cleaner and other sampling equipment

Table 1. Average concentration of parameters measured (average, $n = 30$) in household dust and street dust (average, $n = 30$). r- and p-value indicate the correlation between chemical compositions in household dust and street dust

Parameter	Unit	Household dust	Street dust	r-value	p-value (one-tailed)
Water content	%	2.76 ± 1.07	0.56 ± 0.66	0.28	0.06
Organic substances content	%	20.99 ± 9.85	2.88 ± 0.72	-0.05	0.39
Chloride	mg·g^{-1}	4.01 ± 2.27	0.57 ± 0.38	0.24	0.09
Nitrate	mg·g^{-1}	0.19 ± 0.12	0.02 ± 0.00	-0.01	0.33
Sulphate	µg·g^{-1}	27.42 ± 1.14	1.43 ± 0.23	-0.14	0.22
Potassium	mg·g^{-1}	2.87 ± 1.59	0.11 ± 0.10	0.65	0.01**
Calcium	mg·g^{-1}	3.25 ± 1.58	0.37 ± 0.29	0.29	0.06
Magnesium	mg·g^{-1}	0.27 ± 0.11	0.02 ± 0.01	0.34	0.03*
Lead	µg·g^{-1}	0.85 ± 0.42	0.43 ± 0.38	-0.22	0.11
Cadmium	µg·g^{-1}	0.19 ± 0.20	0.25 ± 0.37	0.72	0.00**
Iron	µg·g^{-1}	0.69 ± 0.05	0.41 ± 0.05	0.96	0.15
Zinc	µg·g^{-1}	0.43 ± 0.26	0.21 ± 0.07	0.01	0.48
Nickel	µg·g^{-1}	0.83 ± 0.99	0.51 ± 0.93	0.49	0.00**

* = significant at $p < 0.05$.
** = significant at $p < 0.01$.

were cleaned after each sampling. Gloves were worn during all sampling and laboratory procedures. Samples were stored in a cool box after sampling was carried out and in a refrigerator ($0°C$) while waiting for laboratory analysis.

Water Content and Organic Percentage

The percentage of water content of the dust was determined by drying 1 g of dust at $103°C$ for 8 h in an oven. The samples were then cooled in a desiccator before being weighed to obtain the differences in weight before and after they were dried. The percentage of organic composition was determined by burning the dust in a furnace at $600°C$ for 8 h. The dust was then cooled in a desiccator before being weighed to ascertain any difference in weight before and after it was burned.

Anions and Cations Composition

The level of anions (SO_4^{2-}, NO_3^{-}, and Cl^{-}) and cations (Ca^{2+}, Mg^{2+}, and K^{+}) in the dust were analyzed by dissolving 2 g of sample with ultra pure water in a water bath. This was then shaken using an ultrasonic shaker for 1 h. The sample solution was filtered using Whatman cellulose acetate filter paper with pore size of 0.2 μm and filtration apparatus linked to a vacuum pump. The filtered solution was diluted to 100 mL with ultra pure water in a volumetric flask and kept at $4°C$ in a polyethylene bottle until analysis.

Analyses for anions (sulphate, chloride, and nitrate) in dust extracts were conducted by ultra-violet spectro-photometry (Hach DR 2000). Sodium nitrate, sodium chloride, and sodium sulphate (BDH Chemicals) were used as standard solutions for anions determination.

The standard method for sulphate analysis is the turbidimetric procedure whereby, sulphate ion in acidic medium is precipitated with barium chloride ($BaCl_2$) to form barium sulphate. A 25 mL aliquot sample of aqueous extract was pipetted into the UV cell and Reagent SulfaVer® 4 reagent containing $BaCl_2$ was added. The mixture of sample and reagent were allowed to mix for 5 min and the absorbance measured at 450 nm. A similar sample without reagent was used as a blank.

Nitrate was measured by the cadmium reduction method. A 25 mL aliquot sample of aqueous extract was pipetted into the cell and Reagent NitraVer® 5 containing cadmium and N-(1-naphthyl)-ethylenediamine dihy-drochloride was added. Mixture of samples and reagent was shaken vigorously for 1 min. The intensity of the resultant azo-dye solution was measured at 400 nm by using UV spectrometer. Blanks were prepared using deionized water instead of samples.

Chloride was measured by the argentometric method. Potassium chromate was used as an indicator for the reaction between silver nitrate ($AgNO_3$) and chloride anion in neutral or alkaline solutions. A 25 mL aliquot sample of the aqueous sample was pipetted into a conical flask and the pH adjusted to between 7 and 10 using NaOH solution. The samples were then titrated against 0.0141 M $AgNO_3$ by using 1 mL of potassium chromate as an indicator until the colour of solution changed to red (silver chromate). Blanks were prepared using deionized water instead of samples.

The cations Ca^{2+}, K^{+}, and Mg^{2+} were determined by flame atomic absorption spectrophotometry (Perkin Elmer Model 3300). Standard solutions of the ions analyzed were prepared by the dilution of 1000 mg·L^{-1} calcium, potassium, and magnesium standard solutions (BDH Chemicals).

Heavy Metals Composition

To determine heavy metals 2 g of the dust sample were dissolved in a mixture of nitric and perchloric acid (v/v, 16:4) on a hot plate. The sample solution was filtered using Whatman cellulose acetate filter paper with a pore size of 0.2 μm using filtration apparatus linked to a vacuum pump. The filtered solution was diluted to 100 mL with ultra pure water in a volumetric flask and kept at $4°C$ in polyethylene bottle until analysis was conducted. Heavy metal concentration (Ni, Pb, Fe, Cd, and Zn) was determined by a graphite furnace atomic absorption spectrophotometer (Perkin Elmer Model 4100ZL). The standard solutions of the heavy metals analyzed were prepared by appropriate dilution of each heavy metals' standard solution (1000 mg L^{-1}).

Distance of the Houses from a Major Road

The distance of each house from the nearest major road (outside the housing area) was measured using the scale map produced by the local authority, Kajang Town Council.

Statistical Analysis

Correlation coefficient (r), correlation significance and student t-test were conducted using the Statistical Package for the Social Sciences (SPSS) to estimate any notable differences between the mean concentration of indoor dust composition with and without certain activities (smoking, cooking, use of carpets), the concentration of indoor and outdoor dust composition and the correlation of indoor dust composition to the distance from a major road.

Results

Composition of Household Dust and Comparison to Street Dust

The composition of household and street dust at the study areas are summarized in Table 1. The average water content (%) was generally found to be much higher in household dust ($2.76 \pm 1.07\%$) than street dust ($0.56 \pm 0.66\%$). Tropical sunlight with a temperature during the day of more than $30°C$ as well as wind velocity were expected to reduce the percentage of water in the street dust compared to indoor dust, which is usually trapped in the carpet and under or between household furniture.

The composition of organic substances in household dust ($20.99 \pm 9.85\%$) was found to be significantly higher compared to the street dust ($2.88 \pm 0.72\%$), which can be attributed to several sources of household dust such as aerosols from cooking materials, human detritus, building materials, and detergents as used in an indoor environment. These results are quite similar to those produced in a study by Fergusson and Schroeder [32] and Fergusson et al. [33], which indicated significantly higher concentrations of organic matter in indoor dust (approx. 40%) compared to street dust (approx. 9%). The correlation value ($r = -0.05$, $p > 0.05$) (Table 1) showed that organic components in outdoor dust had little influence on the concentration of the organic components in household dust. According to Mariana et al. [34], household dust was also rich in biological species, especially dust mites which contribute to the high composition of organic components in household dust.

The level of the anions studied was relatively higher in the household dust compared to the street dust. The sequence of anions concentration in the household dust was led by chloride (4.01 ± 2.27 mg·g^{-1}) followed by nitrate (0.19 ± 0.12 mg·g^{-1}) and sulphate (27.42 ± 1.14 µg·g^{-1}). The concentration of anions in the street dust showed the same sequence as household dust: chloride (0.57 ± 0.38 mg·g^{-1}), then nitrate (0.02 ± 0.00 mg·g^{-1}) and sulphate (1.43 ± 0.23 µg·g^{-1}). Tap water, which has a chloride concentration of around 7 mg L^{-1} [35], and detergents containing chloride (in particular those used for cleaning activities), were expected to be the main sources of chloride in household dust; while combustion activities in the house were considered to be the main sources of nitrate and sulphate in the indoor environment. Even though anions, as the major component of soil and other anthropogenic sources [36], were expected to be the major contributors of the street dust their solubility by rainwater and the influence of direct sunlight were possible factors influencing a reduced concentration in street dust. The negative and insignificant correlation of nitrate and sulphate in household dust compared to street dust ($p > 0.05$) indicates that the major sources of sulphate and nitrate are indoor sources themselves.

Cations such as potassium (K$^+$), calcium (Ca^{2+}), and magnesium (Mg^{2+}) are the main components of soil [37]; and the components of these elements in household dust are expected to originate from outdoor surface soil and dust. The average concentration of potassium (2.87 ± 1.59 mg·g^{-1}), calcium (3.25 ± 1.58 mg·g^{-1}) and magnesium (0.27 ± 0.11 mg·g^{-1}) in household dust were significantly higher than potassium (0.11 ± 0.10 mg·g^{-1}), calcium (0.37 ± 0.29 mg·g^{-1}) and magnesium (0.02 ± 0.01 mg·g^{-1}) in the street dust. These results indicate that: (1) the cations analyzed can be produced from indoor sources themselves e.g., from building materials, detergents, water, and furniture; and (2) that they can be influenced from outdoor sources and accumulate in an indoor environment. The correlation (Table 1) between cations in the household dust and street dust were found to be significant ($p < 0.05$). The highest r-value in this study was between potassium in household dust and street dust ($r = 0.65$), followed by magnesium ($r = 0.34$) and calcium ($r = 0.29$). These results suggest that outdoor dust can influence the concentration of cations in household dust.

The level of heavy metals in household dust presents the main toxic risk to people, especially young children. Results showed that the concentration of heavy metals studied was relatively higher ($p > 0.05$) in household dust compared to street dust, except in the case of cadmium. Amongst the heavy metals studied (Pb, Cd, Fe, Zn, Ni), lead (Pb) showed the highest average concentration 0.85 ± 0.42 µg·g^{-1} followed by nickel (0.83 ± 0.99 µg·g^{-1}), iron (0.69 ± 0.05 µg·g^{-1}), zinc (0.43 ± 0.26 µg·g^{-1}) and cadmium (0.19 ± 0.20 µg·g^{-1}). These finding are still below the level of heavy metals in indoor dust recorded by several other researchers e.g., Al-Rajhi et al. [15], Rasmussen et al. [30], Al-Momani [38], Chattopadhyay et al. [39], and Yaghi and Abdul-Wahab [40]. The concentration of heavy metals in the street dust followed the sequence of Ni > Pb > Fe > Cd > Zn (Table 3). The levels of metals found in household dust are not considered high enough to constitute a primary risk to human health, although low levels of Cd may lead to bone damage and kidney dysfunction and some clinicians suggest that excessive exposure to various other metals used industrially is associated with varying degrees of central nervous system disorder ranging from

Table 2. Comparison of household dust composition between houses with cooking and without cooking activity in Bandar Baru Bangi and Kajang, Selangor

Parameter	Unit	Cooking activities		Smoking activities		Using carpet	
		With	Without	With	Without	With	Without
Water content	%	2.89 ± 1.16	2.56 ± 0.92	2.87 ± 1.33	2.79 ± 0.80	2.41 ± 0.82	3.24 ± 1.21
Organic substances content	%	23.46 ± 10.92	17.08 ± 6.50	25.54 ± 11.80	18.08 ± 8.32	21.56 ± 11.40	20.20 ± 7.57
Chloride	$mg \cdot g^{-1}$	4.68 ± 2.31	2.95 ± 1.81	4.84 ± 1.88	2.74 ± 1.52	3.48 ± 2.00	4.75 ± 2.48
Nitrate	$mg \cdot g^{-1}$	0.21 ± 0.14	0.15 ± 0.08	0.25 ± 0.16	0.16 ± 0.07	0.16 ± 0.09	0.22 ± 0.15
Sulphate	$\mu g \cdot g^{-1}$	33.09 ± 35.53	18.43 ± 7.86	44.14 ± 43.91	19.73 ± 6.67	30.25 ± 28.71	23.49 ± 29.75
Potassium	$mg \cdot g^{-1}$	3.40 ± 1.43	2.24 ± 1.62	2.74 ± 0.87	2.93 ± 1.86	2.86 ± 1.42	2.91 ± 2.15
Calcium	$mg \cdot g^{-1}$	3.09 ± 1.42	3.52 ± 1.85	3.22 ± 1.27	3.61 ± 1.63	3.30 ± 1.51	3.19 ± 1.74
Magnesium	$mg \cdot g^{-1}$	0.29 ± 0.10	0.22 ± 0.01	0.29 ± 0.11	0.26 ± 0.12	0.25 ± 0.10	0.29 ± 0.12
Lead	$\mu g \cdot g^{-1}$	0.81 ± 0.36	0.92 ± 0.50	0.92 ± 0.35	0.95 ± 0.41	0.85 ± 0.38	0.86 ± 0.48
Cadmium	$\mu g \cdot g^{-1}$	0.19 ± 0.15	0.19 ± 0.27	0.24 ± 0.29	0.09 ± 0.03	0.12 ± 0.12	0.29 ± 0.25
Iron	$\mu g \cdot g^{-1}$	0.69 ± 0.26	0.67 ± 0.34	0.63 ± 0.27	0.69 ± 0.35	0.63 ± 0.30	0.76 ± 0.24
Zinc	$\mu g \cdot g^{-1}$	0.43 ± 0.28	0.42 ± 0.23	0.42 ± 0.31	0.53 ± 0.19	0.49 ± 0.25	0.34 ± 0.26
Nickel	$\mu g \cdot g^{-1}$	0.78 ± 0.97	0.90 ± 1.05	0.73 ± 0.91	0.41 ± 0.30	0.64 ± 0.71	1.09 ± 1.26

Table 3. Correlation (*r*- and *p*-value) between household and distance from the major road

Parameter	*r*-value	*p*-value (one-tailed)
Water content	0.02	0.45
Organic substances content	0.13	0.24
Chloride	0.27	0.07
Nitrate	0.26	0.08
Sulphate	0.00	0.50
Potassium	−0.33	0.07
Calcium	0.30	0.05*
Magnesium	−0.16	0.20
Lead	−0.16	0.20
Cadmium	0.14	0.23
Iron	−0.26	0.08
Zinc	−0.41	0.01**
Nickel	0.00	0.48

* = significant at $p < 0.05$.
** = significant at $p < 0.01$.

learning disorders, to mild forms of dementia, through to Alzheimer's disease. Low levels of heavy metals such as Cd and Pb also interfere with crucial nuclear functions such as DNA replication, DNA repair, and gene expression through competition with nuclear uptake, homeostasis, and the function of essential metal ions [39].

The *r*-value (Table 1) showed a good correlation between iron concentration in household dust and street dust ($r = 0.96$, $p < 0.05$) this is followed by cadmium ($r = 0.72$, $p < 0.05$), nickel ($r = 0.49$, $p > 0.05$) and zinc ($r = 0.01$, $p > 0.05$). Lead, on the other hand, had a negative correlation ($r = -0.22$, $p > 0.05$). This result suggests that iron concentration in the household dust was influenced by iron in the street dust. The negative

correlation of lead showed that the concentration of lead in household dust is mostly as result of indoor sources as demonstrated by Fergusson and Kim [22] and Yaghi and Abdul-Wahab [40]. The most significant source of heavy metals in household dust is paint [39]. Tong and Lam [14] report that the color of the wall paints appeared to alter the level of metal in house dust and that yellow and purple paint correlated with a high concentration of lead. The resultant difference, however, was not statistically significant. Total element concentrations in household dust, according to Rasmussen et al. [30], are also likely to be influenced by the relative proportion of biogenic particles (moulds, fungi, and other organic matter), which have an ability to accumulate metals to a high concentration.

Influence of Indoor Activities and Exterior Dust

Previous indoor air quality studies by other researchers, for e.g., Monn et al. [41], Gomzi [42], Tong and Lam [14], Rasmussen et al. [30] suggest that the composition of household dust, especially heavy metals, was related to exterior dust particularly from motor vehicles and interior activities such as cooking and smoking; whilst the use of carpets in an indoor environment acts as a trap for dust accumulation. According to Pedersen et al. [12], heating processes increase the number of sub-micron particles emitted which occurs even at low temperatures starting at 50–100°C and so often present in an indoor environment.

In this study, all parameters were expected to be influenced by combustion activities. The higher concentration of the organic substances sulphate and nitrate in the household dust was most likely a result of smoking and cooking activities (Table 2). In addition, chloride

was found to be higher in household dust in those houses where cooking activities were undertaken, which is most likely due to the high levels of chloride in cooking ingredients. Dust from households where there are smokers, but excluding cooking activities, also results in a high concentration of heavy metals such as cadmium and nickel (Table 2). These results are correlate with those from several other similar studies [41,43,44] which indicate the influence of cooking and smoking activities on the amount of particulate matter and its composition in indoor dust. The results of increasing levels of heavy metals have been demonstrated by Al-Rajhi [15] through increases in the concentration of cadmium.

The use of carpets in houses was found not to change the composition of household dust as shown in Table 2. However, as mentioned in other studies [45,46], carpets do increase the viability of dust mites in household dust. Nevertheless, this study failed to indicate the higher composition of parameters such as organic substances, expected to come from allergens in household dust collected from those houses with carpets.

The correlation of the household dust compositions related to the distance of the houses from the major road nearest each house (r-values) is shown in Table 3. The correlation analysis sought to investigate the influence of motor vehicles on the concentration of household dust composition as proposed by Madany et al. [23]. The results indicated that only potassium, magnesium, lead, iron, and zinc were found to have negative r-values. These results showed that the concentration of potassium, magnesium, lead, iron, and zinc diminished as the distance of the house from the major road increased. Lead is already regarded as a major pollutant from petrol and diesel engines [47], whilst zinc is produced through the wear of vehicle tyres [48]. However, the correlation was not statistically significant which indicates that the influence of motor vehicles on household dust in the semi-urban area is undetermined.

Other parameters such as potassium and magnesium, in addition to as zinc and iron are usually associated with soil dust [36]. Rain water is capable of transporting this kind of dust to the street through water flow where it eventually dries. This kind of dust is expected to have greater influence on the amount of dust generated in the housing area through the movement of motor vehicles compared to the dust from the motor vehicles alone.

Conclusion

The composition of household dust versus street dust in 31 houses in Bandar Baru Bangi and Kajang, Selangor showed that household dust has a distinctly higher concentration of the analytes studied compared to street dust. It was concluded that the dust generated within the house itself (e.g., from building materials such as paints, and activities such as smoking and cooking) was an important source of exposure for certain pollutants. The concentration of cations in indoor dust (potassium, magnesium, and calcium) indicates that the possibility of transport from soil dust to the indoor environment. Nevertheless, the compositions of pollutants in household dust in the study area hardly correlate to the traffic related factors from the nearby road.

The results of this study suggest that further research could be conducted into the influence of indoor activities, equipment, and chemicals on the amount of indoor air pollutants. Activities such as smoking and cooking need to be considered as factors which contribute to the amount of certain pollutants, e.g., organic substances and sulphate, in the indoor environment. This suggests that these activities may need to be limited or conducted under more suitable conditions (for example with good ventilation) in the indoor environment. Even though the amount of pollutants e.g., heavy metals recorded in this study far below the results of other studies, there is still a need to correlate the amount of indoor air pollutants to human health indicators due to the specific conditions existing in Malaysia.

References

1 Chan AT: Indoor-outdoor relationships of particulate matter and nitrogen oxides under different outdoor meteorological conditions: Atmos Environ 2002;36:1543–1551.
2 Wu C-F, Delfino RJ, Floro JN, Quintana PJE, Samimi BS, Kleinman MT, Allen RW, Liu L-JS: Exposure assessment and modeling of particulate matter for asthmatic children using personal nephelometers: Atmos Environ 2005;39:3457–3469.
3 Jenkins PL, Phillips TJ, Mulberg EJ, Hui SP: Activity patterns of Californians: Use of and proximity to indoor pollutant sources: Atmospheric Environment - Part A General Topics 1992;26A:2141–2148.
4 Hays SM, Gobbell RV, Gamick NR: Indoor Air Quality. Solution and Strategies. New York, McGraw-Hill Inc., 1995.

5 Brooks BO, David WF: Understanding Indoor Air Quality. Boca Raton, CRC Press, 1992.

6 Brims F, Chauhan AJ: Air quality, tobacco smoke, urban crowding and day care: modern menaces and their effects on health: Ped Infectious Dis J 2005;24:S152–156, discussion S156–157.

7 Bhargava A, Khanna RN, Bhargava SK, Kumar S: Exposure risk to carcinogenic PAHs in indoor-air during biomass combustion whilst cooking in rural India: Atmos Environ 2004; 38:4761–4767.

8 Tervahattu H, Lodenius M, Tulisalo E: Effects of the reduction of cement plant pollution on the foliar and bark chemical composition of Scots pine: Boreal Environ Res 2001;6: 251–259.

9 He C, Morawska L, Hitchins J, Gilbert D: Contribution from indoor sources to particle number and mass concentrations in residential houses: Atmos Environ 2004;38: 3405–3415.

10 Dall'Osto M, Harrison RM, Charpantidou E, Loupa G, Rapsomanikis S: Characterisation of indoor airborne particles by using real-time aerosol mass spectrometry: Sci Total Environ 2007;384:120–133.

11 Pedersen EK, Bjørseth O, Syversen T, Mathiesen M: Emissions from heated indoor dust: Environ Int 2001;27:579–587.

12 Pedersen EK, Bjørseth O, Syversen T, Mathiesen M: Physical changes of indoor dust caused by hot surface contact: Atmos Environ 2001;35:4149–4157.

13 Wichmann J, Janssen NAH, Van Der Zee S, Brunekreef B: Traffic-related differences in indoor and personal absorption coefficient measurements in Amsterdam, the Netherlands: Atmos Environ 2005;39:7384–7392.

14 Tong STY, Lam KC: Home sweet home? A case study of household dust contamination in Hong Kong: Sci Total Environ 2000;256: 115–123.

15 Al-Rajhi MA, Seaward MRD, Al-Aamer AS: Metal levels in indoor and outdoor dust in Riyadh, Saudi Arabia: Environ Int 1996;22: 315–324.

16 Lee AKY, Lau APS, Cheng JYW, Fang M, Chan CK: A study on major inorganic ion composition of atmospheric aerosols: J Environ Biol 2007;28:241–244.

17 Santoso M, Hopke PK, Hidayat ALDD: Sources identification of the atmospheric aerosol at urban and suburban sites in Indonesia by positive matrix factorization: Sci Total Environ 2008;397:229–237.

18 Finlayson-Pitts BJ, Pitts JN: Chemistry of the Upper and Lower Atmosphere, Theory, Experiments and Application. San Diego, Academic Press, 2000.

19 Pakkanen TA, Loukkola K, Korhonen CH, et al: Sources and chemical composition of atmospheric fine and coarse particles in the Helsinki area: Atmos Environ 2001;35: 5381–5391.

20 Demirak A: The influence of a coal-fired power plant in Turkey on the chemical composition of rain water in a certain region: Environ Monitor Assessment 2007;129: 189–196.

21 Adgate JL, Willis RD, Buckley TJ, et al: Chemical mass balance source apportionment of lead in house dust: Environ Sci Technol 1998;32:108–114.

22 Fergusson JE, Kim ND: Trace elements in street and house dusts: Sources and speciation: Sci Total Environ 1991;100:125–150.

23 Madany IM, Akhter MS, Al Jowder OA: The correlations between heavy metals in residential indoor dust and outdoor street dust in Bahrain: Environ Int 1994; 20:483–492.

24 Chen YC, Yuanhui Z, Barber EM: A dynamic method to estimate indoor dust sink and source: Building Environ 2000;35: 215–221.

25 Lisiewicz M, Heimburger R, Golimowski J: Granulometry and the content of toxic and potentially toxic elements in vacuum-cleaner collected, indoor dusts of the city of Warsaw: Sci Total Environ 2000;263:69–78.

26 Diaz JV, Koff J, Gotway MB, Nishimura S, Balmes JR: Case report: A case of wood-smoke-related pulmonary disease: Environ Hlth Perspect 2006;114:759–762.

27 Mommers M, Jongmans-Liedekerken AW, Derkx R, et al: Indoor environment and respiratory symptoms in children living in the Dutch-German borderland: Int J Hyg Environ Hlth 2005;208:373–381.

28 Bodin A, Fischer T, Bergh M, Nilsson JLG, Karlberg A-T: Skin irritation from air-oxidized ethoxylated surfactants: Contact Dermatitis 2000;43:82–89.

29 Matson U: Indoor and outdoor concentrations of ultrafine particles in some Scandinavian rural and urban areas: Sci Total Environ 2005;343:169–176.

30 Rasmussen PE, Subramanian KS, Jessiman BJ: A multi-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada: Sci Total Environ 2001;267: 125–140.

31 Wilson WE, Chow JC, Claiborn C, Fusheng W, Engelbrecht J, Watson JG: Monitoring of particulate matter outdoors: Chemosphere 2002;49:1009–1043.

32 Fergusson JE, Schroeder RJ: Lead in house dust of Christchurch, New Zealand: Sampling, levels and sources: Sci Total Environ 1985; 46:61–72.

33 Fergusson JE, Forbes EA, Schroeder RJ, Ryan DE: The elemental composition and sources of house dust and street dust: Sci Total Environ 1986;50:217–221.

34 Mariana A, Ho TM, Gendeh BS, Iskandar H, Zainuldin-Taib M: First report on sensitization to allergens of a house dust mite, Suidasia pontifica (Acari: Saproglyphidae): Southeast Asian J Tropical Med Pub Hlth 2000;31: 722–723.

35 Saad B, Pok FW, Sujari ANA, Saleh MI: Analysis of anions and cations in drinking water samples by Capilllary Ion Analysis: Food Chem 1998;61:249–254.

36 Li X, Zhang G, Dong J, Zhou X, Yan X, Luo M: Estimation of critical micelle concentration of anionic surfactants with QSPR approach: J Mol Structure (Theochem) 2004; 710:119–126.

37 Plaisance H, Galloo JC, Guillermo R: Source identification and variation in the chemical composition of precipitation at two rural sites in France: Sci Total Environ 1997; 206:79–93.

38 Al-Momani IF: Trace elements in street and household dusts in Amman, Jordan: Soil Sediment Contam 2007;16:485–496.

39 Chattopadhyay G, Lin KCP, Feitz AJ: Household dust metal levels in the Sydney metropolitan area: Environ Res 2003;93: 301–307.

40 Yaghi B, Abdul-Wahab SA: Levels of heavy metals in outdoor and indoor dusts in Muscat, Oman: Int J Environ Studies 2004; 61:307–314.

41 Monn C, Fuchs A, Högger D, Junker M, Kogelschatz D, Roth N, Wanner H-U: Particulate matter less than 10 μm (PM_{10}) and fine particles less than 2.5 μm ($PM_{2.5}$): Relationships between indoor, outdoor and personal concentrations: Sci Total Environ 1997;208:15–21.

42 Gomzi M: Indoor air and respiratory health in preadolescent children: Atmos Environ 1999;33:4081–4086.

43 Kamens R, Lee C-T, Wiener R, Leith D: A study to characterize indoor particles in three non-smoking homes: Atmos Environ - Part A General Topics 1991;25 A:939–948.

44 Chao CYH, Tung TCW, Burnett J: Influence of different indoor activities on the indoor particulate levels in residential buildings: Indoor Built Environ 1998;7:110–121.

45 Obendorf SK, Lemley AT, Hedge A, Kline AA, Tan K, Dokuchayeva T: Distribution of pesticide residues within homes in central New York State: Arch Environ Contam Toxicol 2006;50:31–44.

46 Causer SM, Lewis RD, Batek Sr JM, Ong K-H: Influence of Wear, Pile Height, and Cleaning Method on Removal of Mite Allergen from Carpet: J Occup Environ Hyg 2004;1:237–242.

47 Lough GC, Schauer JJ, Park J-S, Shafer MM, Deminter JT, Weinstein JP: Emissions of metals associated with motor vehicle roadways: Environ Sci Technol 2005;39: 826–836.

48 Gustafsson M, Blomqvist G, Gudmundsson A, Dahl A, Swietlicki E, Bohgard M, Lindbom J, Ljungman A: Properties and toxicological effects of particles from interaction between tyres, road pavement and winter traction material: Sci Total Environ 2008; 393:226–240.